

Residual stress determination by X-ray diffraction in tungsten thin films

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In this study, the complete residual stress tensor has been determined by X-ray diffraction, using the $\sin^2\psi$ method, in 1000 and 2500 Å tungsten thin films deposited by ion beam sputtering on a silicon monocrystal. In the first case, we found very high tension stresses (about 1.5 GPa) for the as-prepared state and important compressive stresses (about -1.3 GPa) after an implantation with a dose of 10^{16} Xe^{2+} ions/cm² at 320 keV. In the second case, the film was almost detached from its substrate and the stresses were compressive (about -0.9 GPa). In all cases, the free-stress lattice parameter was different from the bulk one, indicating significant differences between the microstructure of these thin tungsten films and the one of the bulk. The size of the coherent domains of diffraction was also determined and was found to largely vary from one case to the other.

1. Introduction

The development of thin films is constantly increasing because of their electrical, optical, mechanical, tribological properties, and their corrosion resistance. Residual stresses influence the majority of these properties and their knowledge is therefore very important. The subject has been studied by various methods such as curvature measurements [1–3], symmetrical X-ray diffraction [4], Raman spectroscopy [5], photoelectric

effect [6], and non-symmetrical X-ray diffraction using the $\sin^2\psi$ method [7]. Contrarily to the other methods, the last one is the only one which allows the whole stress tensor to be determined without any hypothesis (except the necessary $\sigma_{33} = 0$, where 3 is the axis normal to the film surface (see fig. 1). This method is used in this study. We will recall here its main principles and for a complete presentation, see for example refs. [7–10].

2. Principles of the $\sin^2\psi$ method

The method is based on the derivative of the Bragg law

$$2d \sin \theta = \lambda, \quad (1)$$

which gives

$$\Delta d/d = \epsilon_{\phi\phi} = -\cos \theta \Delta \theta, \quad (2)$$

where ϕ and ψ are the Euler angles (see fig. 1), d is the interreticular distance of the diffracting family $\{hkl\}$, $\Delta \theta = \theta - \theta_0$, θ being the diffraction angle of the $\{hkl\}$ planes in the stressed film

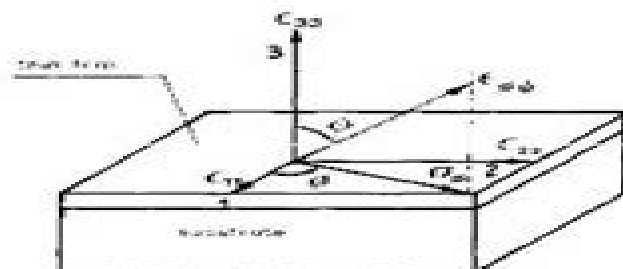


Fig. 1. Referential used in our study.

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Practical Residual Stress Measurement Methods Gary S. Schajer, 2013-08-01 An introductory and intermediate level handbook written in pragmatic style to explain residual stresses and to provide straightforward guidance about practical measurement methods Residual stresses play major roles in engineering structures with highly beneficial effects when designed well and catastrophic effects when ignored With ever increasing concern for product performance and reliability there is an urgent need for a renewed assessment of traditional and modern measurement techniques Success critically depends on being able to make the most practical and effective choice of measurement method for a given application *Practical Residual Stress Measurement Methods* provides the reader with the information needed to understand key residual stress concepts and to make informed technical decisions about optimal choice of measurement technique Each chapter written by invited specialists follows a focused and pragmatic format with subsections describing the measurement principle residual stress evaluation practical measurement procedures example applications references and further reading The chapter authors represent both international academia and industry Each of them brings to their writing substantial hands on experience and expertise in their chosen field Fully illustrated throughout the book provides a much needed practical approach to residual stress measurements The material presented is essential reading for industrial practitioners academic researchers and interested students Key features Presents an overview of the principal residual stress measurement methods both destructive and non destructive with coverage of new techniques and modern enhancements of established techniques Includes stand alone chapters each with its own figures tables and list of references and written by an invited team of international specialists *Introduction to the Characterization of Residual Stress by Neutron Diffraction* M.T.

Hutchings, 2005-02-28 Over the past 25 years the field of neutron diffraction for residual stress characterization has grown tremendously and has matured from the stage of trial demonstrations to provide a practical tool with widespread applications in materials science and engineering While the literature on the subject has grown commensurately it has also remained

Structural and Residual Stress Analysis by Nondestructive Methods V. Hauk, 1997-11-10 The field of stress analysis has gained its momentum from the widespread applications in industry and technology and has now become an important part of materials science Various destructive as well as nondestructive methods have been developed for the determination of stresses This timely book provides a comprehensive review of the nondestructive techniques for strain evaluation written by experts in their respective fields The main part of the book deals with X ray stress analysis XSA focussing on measurement and evaluation methods which can help to solve the problems of today the numerous applications of metallic polymeric and ceramic materials as well as of thin film substrate composites and of advanced microcomponents Furthermore it contains data results hints and recommendations that are valuable to laboratories for the certification and accreditation of their stress analysis Stress analysis is an active field in which many questions remain unsettled Accordingly

unsolved problems and conflicting results are discussed as well The assessment of the experimentally determined residual and structural stress states on the static and dynamic behavior of materials and components is handled in a separate chapter Students and engineers of materials science and scientists working in laboratories and industries will find this book invaluable Canadian Metallurgical Quarterly ,2008 **Fracture, Fatigue, Failure, and Damage Evolution, Volume 5** Jay Carroll,Samantha Daly,2014-08-21 Fracture Fatigue Failure and Damage Evolution Volume 5 Proceedings of the 2014 Annual Conference on Experimental and Applied Mechanics the fifth volume of eight from the Conference brings together contributions to this important area of research and engineering The collection presents early findings and case studies on a wide range of areas including Mixed Mode Fracture I Emphasis on Modeling Mixed Mode Fracture II Emphasis on Experimental Measurements Full Field Measurements of Fracture Microscale Microstructural Effects on Mechanical Behavior I Nanoscale Effects Microscale Microstructural Effects on Mechanical Behavior II MEMS Microscale Microstructural Effects on Mechanical Behavior III Microstructure Microscale Microstructural Effects on Mechanical Behavior IV Shape Memory Alloys Fracture Fatigue of Composites Fracture Fatigue for Engineering Applications Wave Based Techniques in Fracture Fatigue I Wave Based Techniques in Fracture Fatigue II Acoustic Emissions **SAE Technical Paper Series** ,1964 Online version Technical papers portion of the SAE Digital Library references thousands of SAE Technical Papers covering the latest advances and research in all areas of mobility engineering including ground vehicle aerospace off highway and manufacturing technology Sample coverage includes fuels and lubricants emissions electronics brakes restraint systems noise engines materials lighting and more Your SAE service includes detailed summaries complete documents in PDF plus document storage and maintenance **Structural Integrity of Fasteners Including the Effects of Environment and Stress Corrosion Cracking** Pir M. Toor,Joseph Barron,2007 Annotation Eleven peer reviewed papers provide the latest information on the structural integrity of fasteners including the effect s of environmental and stress corrosion cracking For Sections cover Fatigue and Crack Growth Experimental Techniques three papers cover the development of a fastener structural element test for certifying navy fasteners material experimental crack growth behavior for aerospace application and influence of cold rolling threads before and after heat treatment on the fatigue resistance of high strength coarse thread bolts for multiple preload conditions Design Environmental Effects two papers examined the relationship between the tightening speed with friction and clamped load and the optimum thread rolling process that improves SCC resistance to improve quality of design Fatigue and Crack Growth Analytical Techniques three papers describe current analytical techniques for fatigue and crack growth evaluations of fasteners a numerical crack growth model using the finite element analysis generated stress field and s the resistance of high strength fine thread bolts for multiple preload conditions Design Consideration focuses on the comprehensive nonlinear 3D finite element model to simulate a displacement controlled for riveted structure state of the art fatigue crack growth analysis techniques which are used in various industries

to damage tolerance evaluation of structures and the material stress state within the thread of the bolt and on each parameter affecting the structural integrity of a bolted joint Practical Applications of Residual Stress Technology C. O. Ruud, 1991 Includes papers on the effects of residual stress on materials properties Measurement methods and techniques are covered in a number of papers that describe applications of X ray diffraction Barkhausen noise ultrasonic velocity and neutron diffraction Prediction of residual stresses described include applications to metal welding forging and forming as well as ceramic matrix composites and those developed by manufacturing processes *British Journal of Non-destructive Testing*, 1991 Residual Stresses A. Niku-Lari, 2014-05-17 Residual Stresses presents a collection of articles that provides information regarding the use of surface treatment systems It discusses the developments in the technology and application of surface treatment It addresses the influence of minor stresses on the performance of materials Some of the topics covered in the book are the introduction to self equilibrating stresses existing in materials the stresses that form as a consequence of welding the stresses made by machining and the mechanical generation of self stresses The analysis of the stresses caused by thermal and thermochemical surface treatments is covered The minor stresses in composite materials are discussed The text describes the stresses in uranium and uranium alloys The Trepan or ring core method centre hole method and Sachs method are presented A chapter of the volume is devoted to the measurement of residual stresses Another section of the book focuses on the application of shot peened plates to residual stress distribution The book will provide useful information to mechanics engineers students and researchers **Residual Stress Effects on Fatigue and Fracture Testing and Incorporation of Results Into Design** Michael R. Mitchell, 2007 Eleven peer reviewed papers written by experts in their field provide an understanding of residual stresses fatigue crack growth fatigue lifetime predictions and their effect on structural integrity Residual stresses can be present due to processing and manufacturing of materials and structures so it is imperative to understand how and why they can influence the test data that we used in structural design methodologies Residual stresses may also be intentionally engineered into structures in attempts to improve fatigue life and it is equally important that designers understand how to account for these potential effects on fatigue life Publisher's website *Subject Guide to Books in Print*, 1975 **The Effect of Nuclear Radiation on Structural Metals** Frederic R. Shober, 1961 The effect of fast neutron 1 Mev irradiation on the mechanical properties of structural metals and alloys was studied Although the yield strengths and ultimate tensile strengths are increased substantially for most materials the ductility suffers severe decreases This report presents these changes in properties of several structural metals for a number of neutron exposures within the 10^{-10} to the 10^{-18} power to 5×10^{-10} to the 21 st power n sq cm range Data summarizing these effects on several classes of materials such as carbon steels low alloy steels stainless steels Zr base alloys ni base alloys Al base alloys and Ta are given Additional data which show the influence of irradiation temperatures and of post irradiation annealing on the radiation induced property changes are also given and discussed Increases as great as 175% in yield strength 100% in

ultimate strength and decreases of 80% in total elongation are reported for fast neutron exposures as great as 5 10 to the 21st power n sq cm Author **S.A.E. Handbook** ,1991 *Materials & Methods* ,1946 International Books in Print ,1986 Materials Evaluation ,1983 Welding Journal ,1944 Current welding literature included in each volume

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